NASA TECHNICAL NOTE

NASA TN D-4009

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NASA TN D-4009

EFFECTIVENESS OF ENVIRONMENT-SIMULATION TESTING FOR SPACECRAFT

by John C. New and A. R. Timmins

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1967

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ABSTRACT

The philosophy and purpose of ground simulation tests for unmanned spacecraft, as used at the Goddard Space Flight Center, is reviewed. Laboratory test results are presented from 16 prototype and 48 flight spacecraft. The summarized results show a four-to-one ratio in problems per spacecraft for prototype compared to flight models, and for both models the simulated space test has revealed the largest number of problems. A comparison of the number of space problems with test problems on the same spacecraft shows no correlation and shows that 100% trouble-free operation was not obtained on any spacecraft. Data from simulated space testing of 270 experiments for an observatory program show an exponential relationship of malfunctions with time. The curve can be used to estimate the number of problems that will be detected by varying the test time, but cannot be extrapolated to long-term (days) testing. The data from the systems test of a complete observatory under simulated space conditions show failures occurring after 12 days of testing and verify the need for long-term systems tests.

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INTRODUCTION

Prior to the space age, test and evaluation usually involved large sample sizes from which probabilities could be assigned to the chances for success of an item, a weapon, or weapon system. Working with spacecraft, however, presents a much different problem. Here the sample size amounts to two or possibly three items. Another major difference is that the item itself is tested, any difficulties or malfunctions remedied, and the tested item itself flown. Conventional statistics are not amenable to demonstrating a stated reliability. Under these conditions, it was necessary to develop a new approach to testing and a new test philosophy. This paper reviews the test philosophy used at Goddard Space Flight Center (GSFC) and presents data which summarizes the entire test and evaluation experience of the Center. The latter includes experience from industry-conducted programs.

TEST AND EVALUATION PHILOSOPHY

It would be ideal if the space environment could be reproduced exactly for spacecraft evaluation. However, economic, technological, and terrestrial limitations prevent achievement of this ideal objective. The following examples show the kinds of limitations indicated. To simulate exactly the cold of space requires a facility capable of providing a temperature of 4°K over an area of 200 square feet (and up). Careful analysis of the effect of compromising this temperature shows that a practical, economic answer is possible. By using liquid nitrogen (boiling point, 77°K) as the cryogenic fluid, the space thermal radiation environment can be duplicated with an error of less than one percent. Some of the technological problems, however, do not have such a desirable solution. In the case of the micrometeoroid and energetic particles space environments, a lack of facilities requires that these environments be dealt with from an experience and theoretical standpoint. The same is true for the terrestrial limitations where gravity presents a formidable problem in gaining test information on weightlessness. It is then necessary to devise a philosophy of testing which accommodates these restraints and achieves a high degree of assurance that the spacecraft will be successful.

*Presented at the American Institute of Aeronautics and Astronautics and the American Astronautical Society *Stepping Stones to Mars* Meeting, Baltimore, Maryland, March 1966.

At GSFC, the test philosophy is to concentrate on total systems testing under environmentally induced stress levels for sufficient time to detect most deficiencies. To qualify a given design, a prototype system is tested at augmented stress levels and durations. The actual flight system is tested at environmental stress levels which would not be expected to be exceeded more than once in 20 cases. For design qualification tests on prototypes, it is customary to increase vibration amplitudes by 50 percent and durations twice that expected during launch. Predicted temperature extremes are extended 10°C to provide a safety margin. Vacuum simulation is of the order of 10^{-5} to 10^{-8} torr.

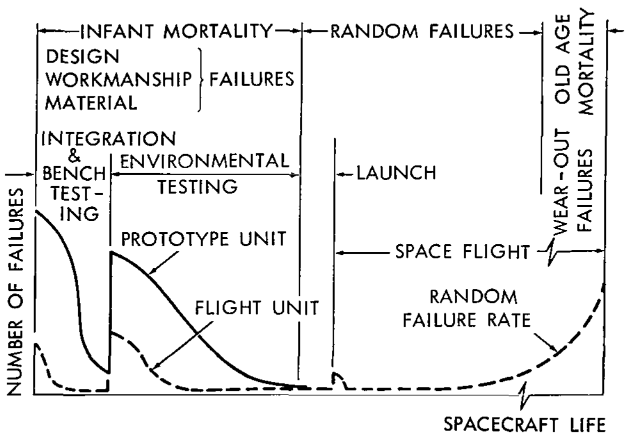

Figure 1—Failure pattern.

Since duplication of the planned orbital life (usually one year) is not economically feasible, the duration of the simulated orbital tests is limited to that time (five to twelve days) necessary to detect and correct failures attributable to "infant mortality." Such tests include temperature extremes, solar simulation, spacecraft positioning for various orbital conditions, and operation of the complete system in all modes of transmission. The test philosophy hypothesizes a failure pattern with time (as shown in Figure 1). The operating time accumulated on a flight unit before launch ranges between 600 and 1200 hours. Complete details on the test philosophy are provided in Reference 1.

TEST AND EVALUATION PROGRAM

Adequate facilities are required to conduct an effective test and evaluation program. Means must be available for determining the effect of shock, vibration, temperature, humidity, and the simulated space environment as well as determining the balance, moment of inertia, and other physical characteristics of the spacecraft. These are the usual environments and characteristics that need to be investigated, and the facilities required for investigation have become somewhat standardized. On the other hand, as spacecraft become larger, and as improved environment simulation becomes necessary, the need for advanced or specialized facilities develops. Three facilities of this type are either in use or under construction at GSFC. One of these is called the Space Environment Simulator (SES). It is a nominal 50,000 cubic foot thermal-vacuum chamber with major working dimensions of 27.5 feet in diameter by 40 feet in height. It has a vacuum capability of 1×10^{-8} torr, liquid nitrogen and gaseous helium cryogenic walls to simulate the cold of space, and a modular solar simulation (mercury-xenon) capability up to 1.5 solar constants. Reference 2 provides further details, and Figure 2 shows one view of the SES. This facility is in use and two tests, one of 44 days duration, have been completed.

Figure 3 shows a facility for magnetic measurements and effects. It is a forty-foot, three-axis Braunbek coil system which can accommodate a complete spacecraft. It has a uniform field

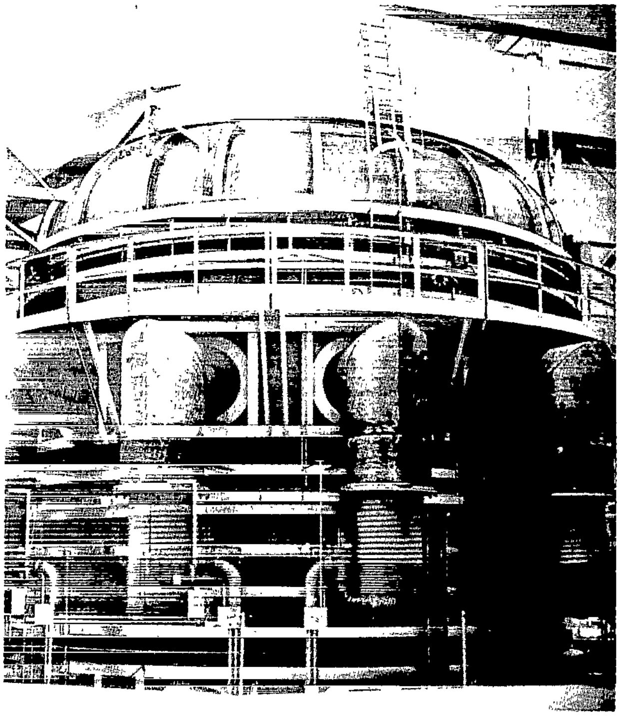

Figure 2—Space Environment Simulator.

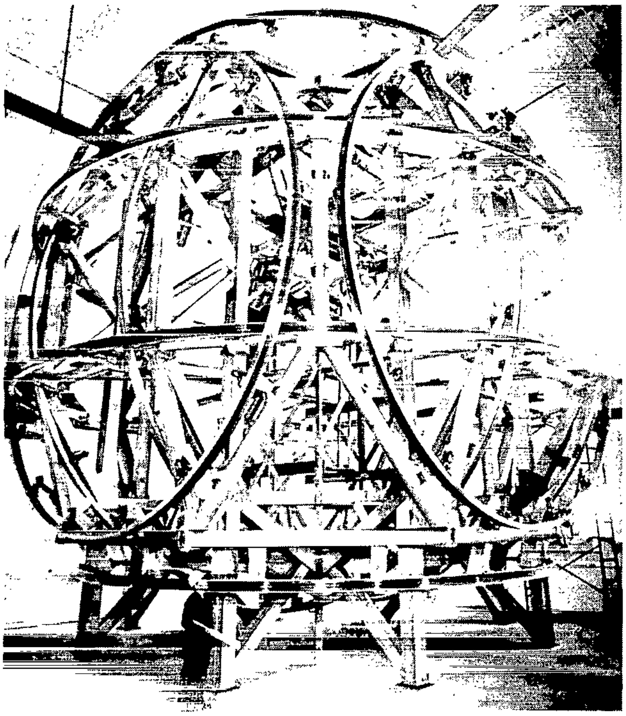

Figure 3—Spacecraft Magnetic Test Facility.

to 0.5 gamma over a six-foot sphere, and five gamma over a 10-foot sphere. It can simulate from zero to twice the earth's magnetic field for simulated space measurements, cancel the earth's magnetic field, check the magnetic moment of the spacecraft, and test active magnetic attitude control systems.

The significance of combined environments has been discussed for some time and is somewhat controversial. The launch environment is a prime example of combined environments, and the simulation of this environment is expected to be both scientifically and practically rewarding. A specialized facility to provide this combined environment, called the Launch Phase Simulator, is shown in Figure 4. It will handle a complete spacecraft weighing up to 5000 pounds, and will be capable of exposing the complete spacecraft to the combined environments of launch acceleration, mechanical motion (three-axis), acoustic excitation, and launch pressure profile in nearly real time.

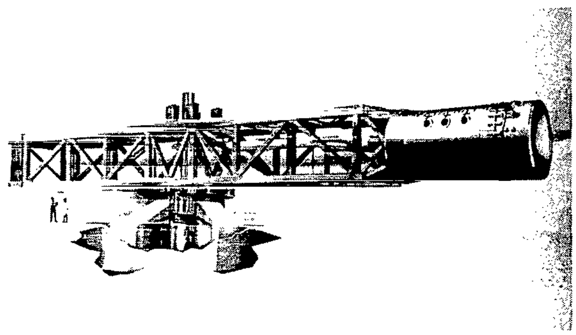

Figure 4—Launch Phase Simulator (Reference 3).

Test and evaluation is only one part of the complete development cycle of a spacecraft program (shown in Figure 5). In this hypothetical case, the time period for test and evaluation is of the order of 12 months. Figure 6 shows actual

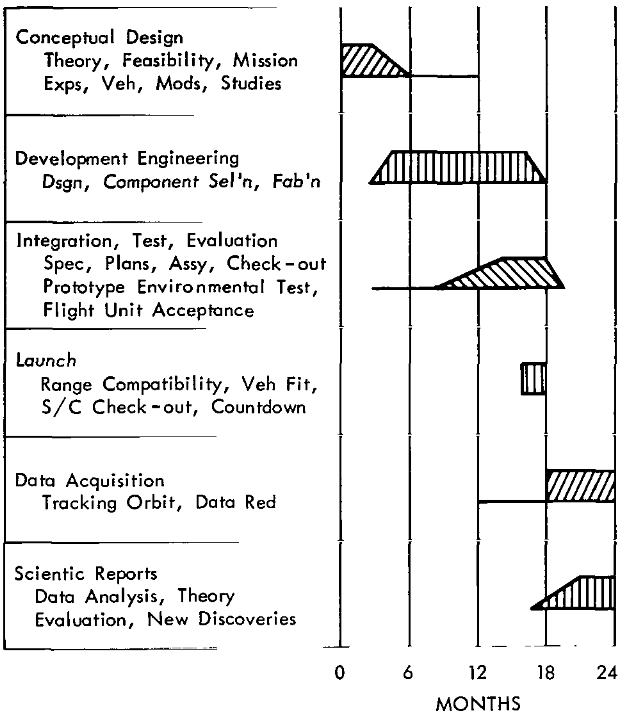

Figure 5—Scientific spacecraft development cycle.

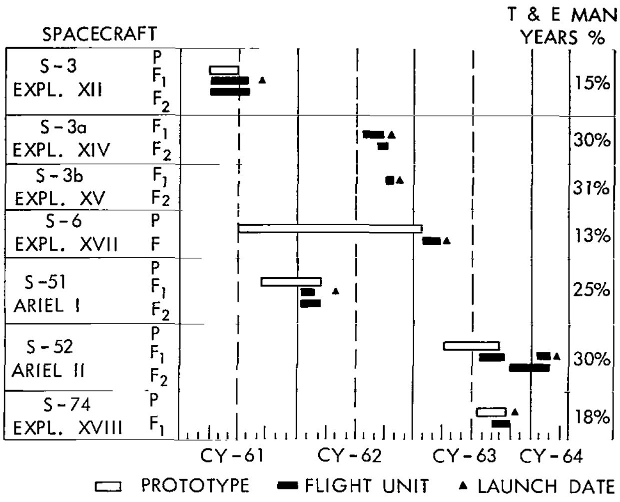

Figure 6—Period for environmental test program.

time for the test and evaluation of 7 spacecraft programs conducted at GSFC. The illustration shows considerable variation in the time for different programs. One special case was accomplished in 30 days. In others, over 18 months may be required. The problem, of course, is to achieve adequate assurance in minimum time.

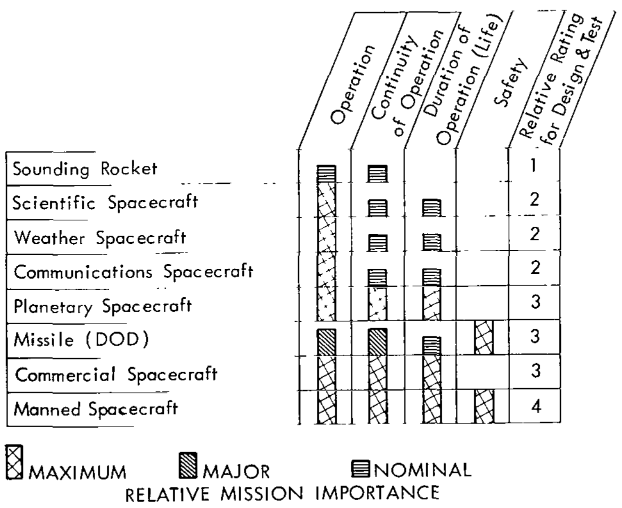

Figure 7—Comparison of spacecraft mission requirements.

To develop an adequate test and evaluation program, consistent with overall program requirements, it is necessary to classify spacecraft performance requirements. For instance, the amount, duration, and extent of testing devoted to a sounding rocket is of a different magnitude than a scientific spacecraft, and the latter is of a different magnitude than a manned spacecraft. Figure 7 compares various requirements for different kinds of spacecraft. With this perspective, the effectiveness of a comprehensive system test policy is reviewed. The test and evaluation results include scientific, meteorology, and communications spacecraft.

EFFECTIVENESS OF ENVIRONMENT SIMULATION TESTS

A good examination of test and evaluation philosophy is provided by dealing with many samples. Such an examination is provided by reviewing the test results of all spacecraft under the direction of GSFC launched in the period of 1960-1964. For this review, the number of problems have been used as a correlative index. A problem is defined as any item which causes a delay or rework during design qualification and acceptance testing of the spacecraft.

The validity of GSFC test philosophy is attested by the results from the evaluation of 16 prototype and 48 flight units. A total of 855 problems were uncovered and corrected, resulting in 27 successful spacecraft or probes and only one major failure - Syncom - in a four-year period. Ten of these spacecraft were designed, developed, and tested at GSFC, and 18 of them were under GSFC management, but the actual design, development, and tests were conducted by prime contractors. The space record, shown in Figure 8, is updated beyond the time period covered by the laboratory test results by including satellites launched through December 1965.

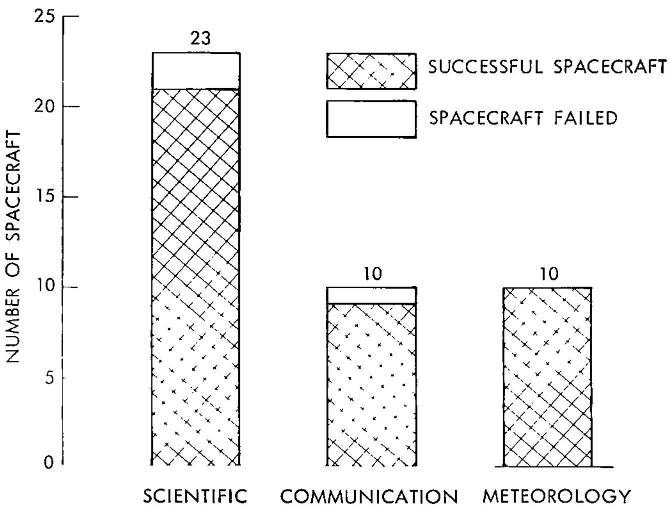

Figure 8—GSFC spacecraft record (43 of 47 launches placed spacecraft in orbit; 40 of 43 spacecraft in orbit were successful).

The summarized information from 64 spacecraft tested at GSFC, or by industry under the management of GSFC, is shown in Figure 9. The summary shows a ratio of approximately 4 to 1 for the number of problems per spacecraft for the prototype model as compared to the flight model. The value of having a prototype spacecraft is amply demonstrated by the large reduction in number of problems per flight spacecraft compared to prototype spacecraft. Although neither the ratio nor its parts are firm values, they can be used as a basis for future comparisons, and possibly as an indication of when the philosophy needs reexamination.

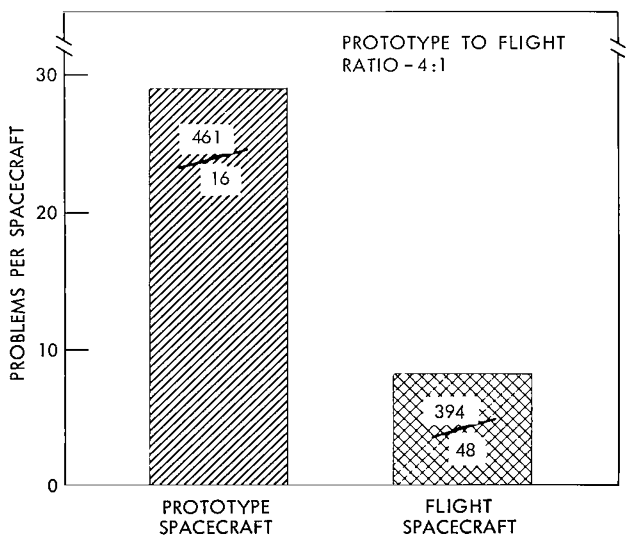

Figure 9—Spacecraft test problems (prototype vs. flight model).

Figure 10 contains the same summarized information subdivided to show a comparison of the results for spacecraft tested at GSFC compared to spacecraft tested by industry. The illustration shows a ratio of approximately 5 to 1 for the GSFC prototype to flight model spacecraft, and a ratio of approximately 3 to 1 for industry. No particular significance is attached to the difference in ratios at the present time. The value of the ratios is to provide a basis for comparing past, present, and future programs. Figure 10 also shows the distribution of problems on each spacecraft by environment. Most of the problems

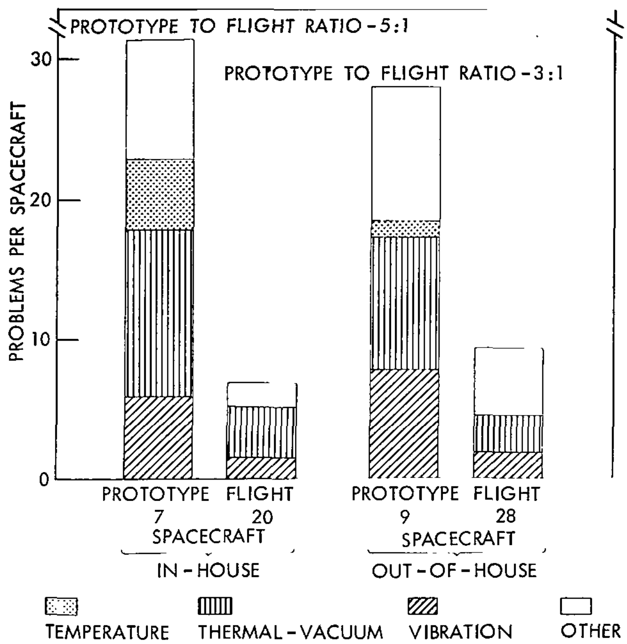

Figure 10—Spacecraft test problems (by environment).

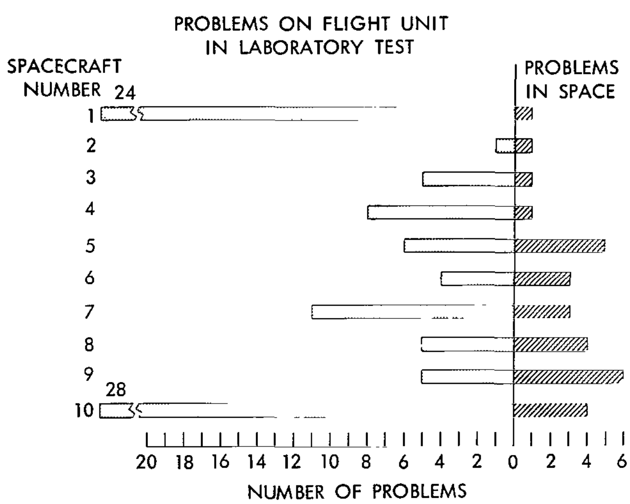

Figure 11—Comparison of space problems with test problems for ten spacecraft.

have been detected in the simulated space environment, and a desirable learning curve is demonstrated by the decrease in the number of problems in this environment from the prototype to the flight model spacecraft. The use of a structural model spacecraft for testing prior to the prototype undoubtedly helps to reduce the number of problems encountered with the prototype in the vibration environment.

Although the number of problems per flight spacecraft looks small by comparison, the results of the first ten spacecraft launched by GSFC are used to determine whether or not all the problems were detected and corrected. A comparison of the number of problems encountered on the flight units in the laboratory compared to the number of problems on the same flight units in space is shown in Figure 11. The number of problems encountered in the laboratory varies from 1 to 28 for various programs. In space, the maximum number of problems encountered is 6. Note that a problem in space is not necessarily identical with a failure in space. A problem is defined here as any performance in space outside of design parameters. This overly severe definition is used to obtain the maximum information available from GSFC space flight experience. Actually, scientific information was obtained from each of the 10 spacecraft shown in Figure 11. Seven of the 10 operated for the full planned lifetime of the satellite, and the other three had lifetimes of 112, 193, and 312 days.

An appraisal of this space flight experience shows several areas in which the information gained can be used to achieve even more successful performance: (a) About 25 percent of the space problems were not subjected to relevant systems tests. For example, in one case the nose cone outgassed and changed the thermal coating properties of the spacecraft. This caused overheating and failure of an experiment. (b) In some cases, a relevant systems test was not possible. For instance, no simulation capability is available for testing stability problems caused by solar radiation pressure or aerodynamic forces at perigee altitudes. (c) Flight devices which cannot be operated during systems tests require special attention. Explosively actuated devices are an example. On one launch an antenna failed to deploy; post-launch investigation revealed a marginal firing current for the explosively actuated device used for deployment.

The space experience analysis is indirect. For many problems the evidence is quite conclusive, for others, post-flight tests have been helpful in assessment, and for others, the reason is obscure or unknown. The preceding paragraph lists some positive areas in which improved performance can be achieved. However, there are other space failures or problems not revealed by the comparatively short-term simulated space tests in the laboratory. These are the problems, apparently time dependent, which occur after a long time (10 to 300 days) in space, but for which no failure analysis is available. The beginning of the wear-out period for space hardware has not been established, but it is significant that the Alouette I satellite has operated satisfactorily for over three years in space, and is still operating.

COST EFFECTIVENESS

A typical development cycle for scientific spacecraft is shown in Figure 6. Test and evaluation occupies a nominal time period of 12 months. This duration, of course, depends upon many factors and, as shown in Figure 7, varies from 1 to 19 months for 7 spacecraft programs. Figure 12 shows actual distribution of the time required to complete 33 programs. The illustration shows that test and evaluation is completed in less than 6 months for the majority of the programs. On the other hand, there are programs that require as much as two years for test and evaluation. With increased emphasis on lower cost, the time period allotted to test and evaluation is being given additional scrutiny. It is of interest to conjecture what effectiveness could be achieved if the long-term programs could be shortened to the norm, and also what savings could be accrued if the norm could be reduced significantly. Considerable savings can be accomplished by shortening the test program, but reliability cannot be sacrificed just for the sake of saving time. Data show that simulated space testing at the systems level accounts for most of the problems during this phase of a system test program. To determine whether the number of these problems could be reduced by additional emphasis on subsystem testing, or whether the problems are of a different nature, subsystem testing of an observatory type program was examined. In the program, 270 experiments were subjected to a simulated space test at subsystem level. Figure 13 shows the distribution of problems encountered as a function of time for the simulated space test. Performance of one of the observatories from this program under a simulated testing environment was also examined. The number of problems with respect to time under the simulated environment is shown in Figure 14. A total of 17 problems

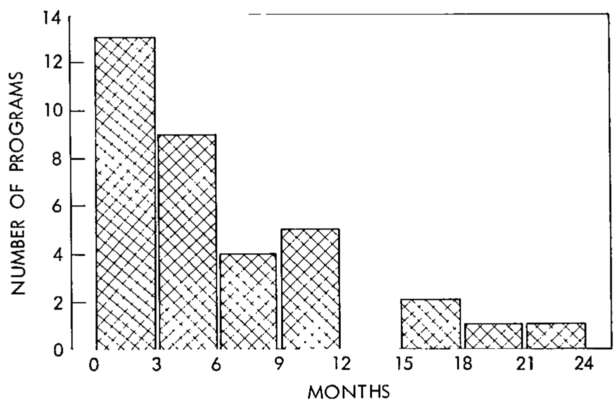

Figure 12—Time for systems testing of spacecraft.

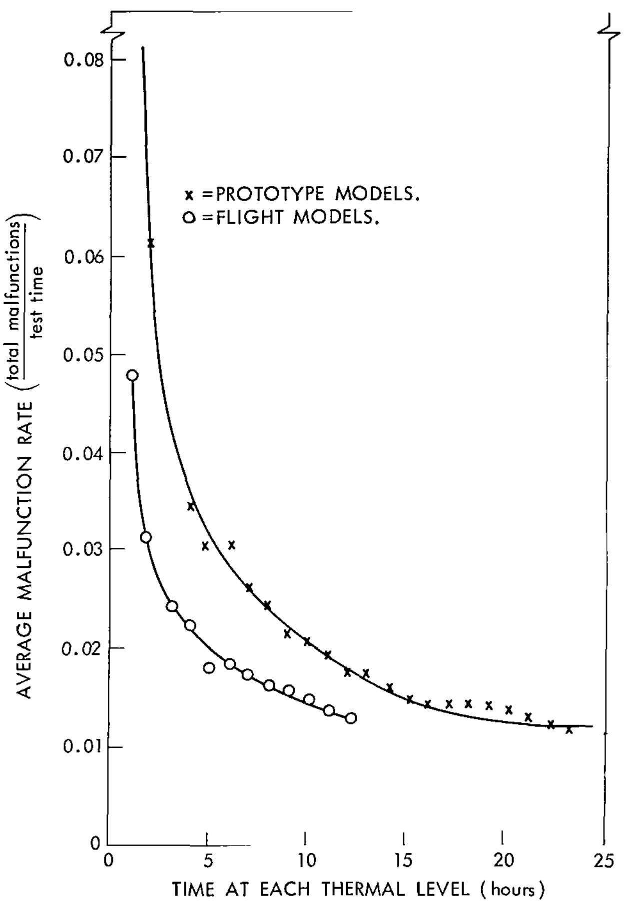

Figure 13—Experiment malfunction rate under simulated space environment.

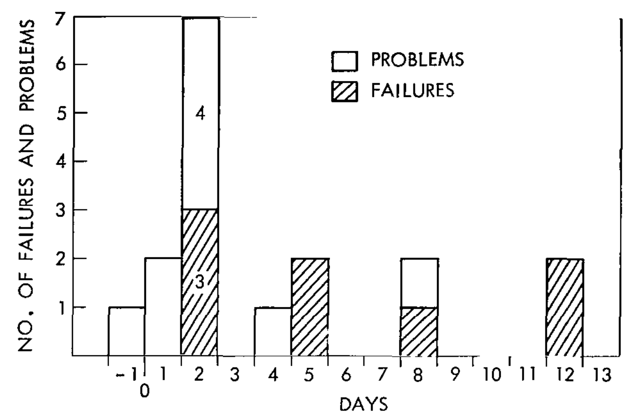

Figure 14—System malfunctions versus time under simulated space environment.

were detected, eight of which were classified as failures. Ten of the 17 problems were with experiments. Of the ten, six had no problems in subsystem test, and the four others did. However, in only one case was the problem possibly associated with the same problem in subsystem testing. The data are not sufficient to make any firm conclusions on the duration and amount of subsystem testing required, but are presented to illustrate the type of information needed for such conclusions. Another aspect of cost effectiveness can be inferred from the data presented. That is, in order to reduce the number of problems discovered in a flight model of a system, it will be necessary to analyze the specific cause of the failures (and the problems) and to have some mechanism to enable the use of this information in other programs at the time when the problem can be circumvented.

CONCLUSIONS

The needs of the space program with its emphasis on limited production of highly complex and highly reliable systems demand a new philosophy of test and evaluation. A philosophy has been developed which places primary emphasis on complete systems tests under realistic environment simulation. Confidence in the design is attained through tests of working prototype systems at augmented stress levels up to 50 percent; confidence in flight readiness is achieved for flight units by tests under the expected environments of launch or space. The laboratory and space results on unmanned scientific spacecraft over a four-year period show the philosophy to be sound. The cost effectiveness of this philosophy is still being evaluated. The philosophy is dependent upon having test articles that can be repaired; a fairly large capital investment in simulation facilities, and a resourceful and competent staff which can respond quickly after problems are detected.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, August 31, 1966
124-12-03-01-51

REFERENCES

1. New, J. C., "Achieving Satellite Reliability Through Environmental Tests," NASA Technical Note D-1853, July 1963.

2. Cope, D. C., "Problems in the Construction of a Space Environment Simulator," NASA Technical Note D-1917, March 1964, also in: *Proc. of the Inst. of Environmental Sci.*, 1963, pp. 251-256.

3. Kirchman, E. J., "Launch Phase Simulator," in: *Proc. of AIAA Space Simulation Conf.*, 1964, Pasadena, California, pp. 275-287.

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